Important Interactions between Calcium (Ca) and Magnesium (Mg) in The Nutrition and Health of Growing Swine: A Review

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Abstract—Calcium and Mg are very essential macro-minerals in the nutrition and welfare in all growing animals, especially in the pig. Ca and Mg soluble ions share chemical similarities as they are both class 11b alkaline earth metals. Therefore, they demonstrate intriguing interactions in the nutrition and health of the growing pig. This paper attempts to describe some insights into the interactions existing between Ca and Mg ions involving strict hormonal regulations and other dietary factors to maintain their homeostasis.

Keywords—*Calcium, magnesium, ions, interactions and swine*

INTRODUCTION

Calcium and Magnesium are both essential nutrients for all animal species. Ca and Mg soluble ions share chemical similarities as they are both class 11b alkaline earth metals. Therefore, they do demonstrate some significant interactions in the nutrition and health of the growing swine. For instance, Ca and Mg are major components of the skeletal system in addition to other physiological functions they perform. Magnesium is also the most abundant mineral constituent of bone after Ca and phosphorus (P) (NRC, 1998). The similar chemical properties that Ca and Mg possess are known to trigger significant interactions between their soluble ions in their metal-ion interactions that can significantly impact the nutrition and health of growing swine from physiological standpoint. This similar biochemical state of Ca and Mg may explain in part why these two metal elements are mutually antagonistic (Peo, 1991). This concept will further be explored in relating the significant interactions between them in this review. Furthermore, Ca and Mg are mutually antagonistic to P (Peo, 1991). Thus, Ca and Mg show various dynamic and complex significant interactions in the nutrition and health of the pig. Therefore, these interrelationships among Ca, Mg, P, including the well-coordinated interplay of physiological cascades involving parathyroid hormone (PTH) and vitamin D in bone health and turnover along with other plant/animal factors will be used to shed more light on Ca and Mg interactions at the physiological and molecular levels in respect to pig nutrition and health.

METAL-ION INTERACTIONS

The major significant interaction existing between Ca and Mg with huge implication on animal health is the interactions between the ions of Ca and Mg. This also forms the nutritional basis upon which their further interactions are hinged. Mg is involved in the regulation of ion channels that transport Ca into and out of cells (Rude, 1998). However, Ca and Mg share a common intestinal Mg transport system (O'Dell, 1997). This may also be used to partially explain the competition between Ca and Mg in intestinal absorption. Nevertheless, excess dietary Ca reduces Mg absorption and status which can potentially induce Mg deficiency resulting in impaired animal growth rate and calcification of soft tissues due to malnutrition of Ca and depressed activity of calcitonin (O'Dell, 1997; Shoback and Sellmeyer, 2010). Thus, the universal observation has been that even mild Mg depletion can perturb Ca homeostasis due to their physiological and biochemical ion interactions by distorting their mutually positive and synergistic correlation on bone density leading to an increased rate of bone loss suggesting that animal growth, health and well-being will be compromised and subsequently exposed such animals to the risks of rickets and osteoporosis. These conditions become worse by the fact that they can further expose the animals to pains and severely impede bone growth therebycausing severely dwarf animal growth rates, giving rise to runts and morbidities; this often leads to animal mortality resulting in huge economic losses on the part of the animal farmer. The reasons for these negative observations are not farfetched. Various independent studies have shown that Mg deficiency may perturb bone mineral homeostasis and hence induce osteoporosis by increasing substance-P (a short-chain peptide that functions as a neurotransmitter, especially in the transmission of pain impulses from peripheral receptors to the central nervous system) and inflammatory cytokine productions, namelytumour necrosis factor alpha (*TNF-α*), interleukin-1 alpha and beta (*IL-1α/β*) and interleukin-6 (*IL-6*) (Rude et al. 2006; Rude et al. 2005; Rude et al. 2004; Rude et al. 2009). Substance-P production is known to increase the release of these cytokines. Cytokines so produced stimulate the recruitment and activity of osteoclasts and consequently increase bone resorption (Shoback and Sellmeyer). These activities compromise animal well-being. More importantly, Mg is a well-documented mitogenic agent for bone cell growth and its deficiency may adversely affect serum insulin-like growth factor 1 (*IGF-1*) that has been demonstrated to be an essential factor in

skeletal growth (Shoback and Sellmeyer). By these actions Ca and Mg interactions can significantly affect the nutrition and health of the growing pig and may also involve their other physiological effects on parathyroid hormone (*PTH*) and vitamin D [*1,25-(OH)$_2$D$_3$*] mechanisms.

Ca, Mg AND PTH INTERACTIONS

Ca and Mg interactions can further impact the nutrition and health of the growing pig through their combined regulatory effects on *PTH* and vitamin D. To this end, Mg deficiency can potentially initiate hypocalcaemia probably due to the failure of the normal heterionic exchange of bone Ca and Mg at the labile mineral surface (Shils, 1997) couple with the fact that Mg influences the Ca-sensing receptor in a manner similar to an acute fall in serum Ca (Brown et al. 1993). Physiologically, due to these actions of Mg, its deficiency impairs the effect of *PTH* receptors on bone and the kidney culminating in the persistence of hypocalcaemia in the presence of increased circulating levels of *PTH* (Rude et al. 2006; Shils, 1997). As these conditions persist the depletion of *PTH* occurs despite adequate intraparathyroid gland hormonal reserves resulting in significant disruption of Ca homeostasis thereby affecting bone turnover (Rude et al. 2006; Shils, 1997). However, this condition can be restored or remedied with administration of adequate Mg resulting in the rapid rise of serum Mg (Shils, 1997) presumably with the restoration of the normal heterionic Ca-Mg exchange (Shils, 1997). Again, the condition does not restore immediately as a result of the time required for bone cell receptors to regain their normal responsiveness to *PTH* which further stresses significant interactions between Ca and Mg in the welfare of growing animal. This may also involve the action of vitamin D.

Ca, Mg and VITAMIN D INTERACTIONS

Ca and Mg work in pari-passu due to their mutual physiological association in maintaining bone health and turnover involving dynamic mechanisms of vitamin D [1,25(OH)$_2$-vitamin D$_3$] and *PTH* organ responses (Saris et al. 2000). Therefore, one of the major modulations by which Mg interacts with Ca is through a complex but well-coordinated regulation of the Ca-Mg-vitamin D-*PTH* cascades. Accordingly therefore, depletion or deficiency of Mg can impair the physiological function of Ca on bone by interfering with the activities of vitamin D even in low serum Ca conditions via impaired *PTH* activity. These findings have been confirmed in different animal species models, including humans (Rude et al. 2006; Fatemi et al; 1991). The underlying feature can be explained on the basis of impaired *PTH* secretion with concomitant loss of the trophic effect of *PTH* on 1,25(OH)$_2$-vitamin D$_3$ synthesis or by a direct effect whereby Mg depletion impedes the response of bone to 1,25(OH)$_2$-vitamin D$_3$. This peculiar effect is also related to the fact that renal 1α-hydroxylase enzyme is unable to efficiently covert 25-(OH) vitamin D to the active physiological form of vitamin D [1,25(OH)$_2$-vitamin D$_3$], since the action of renal 1α-hydroxylase enzyme is Mg-dependent (Shoback and Sellmeyer, 2010). End-organ resistance to *PTH* or 1,25(OH)$_2$-

vitamin D$_3$ as in this case is a clear symptom of compromising animal health and well-being. Plant/animal factors may also be implicated in these organ hormone responses.

Ca, Mg, PTH, VITAMIN D AND PLANT/ANIMAL INTERACTIONS

Other aspects that worth further attention in Ca and Mg interactions and their eventual effects in the nutrition and health of the growing pig is the dietary cum animal involvements. From the fore-discussed, mineral compositions and particularly their forms in the diet are very essential to their absorption and utilization for improved animal growth (NRC, 1998). Accordingly, it has been recently reported that feeding pigs diets with a high mineral solubility will enhance their absorption and assimilation resulting in improved animal performance with minimal mineral excretions in the pig manure with an additional benefit of making swine production more eco-friendly (Petersen, 2010). This also involves feeding animals according to their true mineral requirements based strictly on their sexes, age, genetic potential for growth and their physiological status. This is obvious for the fact that the percentage absorption of the ingested mineral nutrient is strongly determined by its dietary concentration and to a variable extent by promoting or inhibiting dietary components present in the diet (Mineo et al. 2009). This is more so since mineral interactions are very complex yet the primary objective of mineral intake is to obtain the proper balance between them as to enhance their utilization (Liu et al. 2000). Since dietary mineral nutrients cannot be considered separately because of the known interacting forces existing among them, such as that between Ca, Mg and P in addition to their additive effects, different strategies have been adopted in managing mineral nutrition, especially the aspects dealing with dietary components inhibiting their solubility and subsequently affecting their absorption and utilization. To this extent, the effects of dietary fibre and phytate readily come to the fore, particularly that of the latter (NRC, 1998). Here, it is imperative to state that P is the most versatile mineral nutrient in physiological functions than any other mineral (NRC, 1998), yet it's bioavailability of dietary sources are low due to phytate as pigs cannot hydrolyze phytate. The resultant consequence is poor mineral availability due to the formation of phytate-Ca-P-Mg complexes via the chelating influence of phytate in the gastrointestinal tract with huge negative effects on animal performance and the environment (Woyengo et al. 2009). However, the strategies of processing dietary ingredients with the sole aim of modifying their physicochemical forms and render nutrients more available to enzymatic actions for enhanced degradation and absorption have been employed. More especially, the use of addition of exogenous phytase to diets has also been employed. By this nutritional strategy, the inclusion level of 15,000 phytase units per kilogram of diet has been demonstrated recently to efficiently solubilise phytate and significantly improved performance of weanling pigs and digestibility of minerals, including monovalent minerals with up to 85% of phytate-P digested (Kies et al. 2009).

CONCLUSION

The interaction existing between soluble ions of Ca and Mg are very unique. These interactions present important nutritional information in the effective management of the minerals in swine nutrition. The interactions are more importantly dependent on strict hormonal regulations and other components, such as dietary factors. This paper highlights the nature of the interactions in addition to hormones and other dietary factors that regulate them.

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